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A Decade of Bridge Deck Cathodic Protection in Ontario

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A DECADE OF BRIDGE DECK CATHODIC PROTECTION IN ONTARIO

by

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ABSTRACT

Impressed current cathodic protection has been employed as a repair method for reinforced concrete bridge decks in Ontario's Provincial highway system since the mid-1970's. Over thirty decks have received the treatment employing a conductive asphalt overlay. Typical operating characteristics and installation costs are discussed. The condition of three decks under long term protection is described.

INTRODUCTION

Ontario first applied cathodic protection to concrete bridge decks in 1974, when three systems were installed. The designs were modelled on the system developed in California (1), utilizing high silicon iron alloy primary anodes and a secondary anode of coke-asphalt. One deck was protected in 1975 and two more in 1976. The experience with these six installations, which were designated experimental, led to the development of the Ministry's standard method of bridge deck cathodic protection.

The first experimental installation was at Duffins Creek Bridge where one-half the deck was cathodically protected, while the other half was paved with a conventional bituminous surfacing. The system was powered by a constant current rectifier and monitored by surface half-cells and embedded rate-of-corrosion probes. The cathodic protection operated for three years, then both halves of the deck were stripped and sounded for delaminations. The cathodic protection was found to be effective in reducing corrosion in the deck, based both on data from the rate-of-corrosion probes, and the relative degrees of damage on the two halves of the bridge (2).

Modifications were introduced in the installations which followed. Random cracking in the asphalt surfacing at Duffins Creek led to fears regarding the high porosity and possible low stability of the coke asphalt

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mix, though rain immediately following its placement may have been a contributing factor. A modified conductive mix was developed utilizing sand and stone (3). Although the resistivity of the mix was increased, the increase was considered acceptable. The modification reduced the void content of the mix, minimizing the ability of the conductive layer to trap moisture. Experimentation was carried out to determine optimum primary anode spacing.

Comparisons were made between copper-copper sulfate cell measurements on the concrete surface, and voltage measurements on the graphite anodes (which were used in some of the experimental installations), and the conductive mix. This work led to the conclusion that it was feasible to monitor system effectiveness by means of probes buried in the coke-asphalt layer (4). Compact graphite probes, mounted on the concrete surface, were introduced to measure the potential distribution across the deck. It was found that if instant-off potentials were maintained between -0.80 V and -1.25 V, protection of the deck was achieved (5). This became the protection criteria for all Ministry decks - with rectifiers adjusted as necessary to maintain potentials sensed by the voltage probes within this range.

Frequent adjustment of the constant-current rectifiers was necessary to maintain protection levels within the specified range. Constant potential rectifiers were introduced. These were originally controlled by zinc-zinc sulfate reference cells embedded in the deck, but these were found to be unstable and control was switched to a graphite voltage probe.

A significant refinement was introduced in 1976 when all hardware was installed flush with the deck to allow resurfacing of the deck without damage to the components of the cathodic protection system.

The installations in the period 1974-1976 were used to demonstrate the effectiveness of cathodic protection in controlling corrosion in bridge decks and to identify suitable components, a method of control, and a protection criterion. The successful features were then incorporated into a standard method of bridge deck cathodic protection.

STANDARD BRIDGE DECK CATHODIC PROTECTION SYSTEM

The bridge deck cathodic protection system in use in Ontario today evolved from this early work and has remained essentially unchanged since 1976. Ontario's Bridge Deck Rehabilitation Manual (6), outlines options for deck repair and the basis for selection of a repair method. It also includes a detailed design procedure for the standard cathodic system. Installation is covered by standard Special Provisions. Contracts for the work are awarded using the same bidding procedures used for all Ministry construction or rehabilitation work, and are usually awarded to general contractors who subcontract the electrical portion of the work.

To date, there is a total of thirty-one installations across the Province, and these are listed in Table 1. All decks protected after 1977 followed the standard design and construction procedures.

The important features of the system now in use are as follows:

- Primary Anodes. Primary anodes are placed in recesses on the deck, so that the top surface of the anode is flush with the deck surface. The base of the anode is insulated with epoxy, to avoid the occurrence of "hot spots" on the steel directly beneath the anode. The layout of the anodes is a function of deck geometry (6) with one anode provided for every 50-75 m^2 of deck area. Generally three to four anodes are connected to a single feeder line from the rectifier, with those anodes spaced widely so that in the event of power loss

in one feeder line, a large section of the deck is not left unprotected.

Rebar Ground Location. Typically, one ground connection is provided for every 100 m^2 of deck area, with a minimum of four ground connections per structure.

Instrumentation. Both zinc-zinc sulfate reference cells (minimum three per deck) and graphite voltage probes (minimum of four per deck, with additional probes in "problem" areas) are presently used to monitor potentials on the deck. The graphite probes are embedded flush with the concrete surface so that they contact the anode. Additional graphite probes are also embedded at the level of the steel.

Hardware. All wiring from anodes, ground connections and instrumentation is placed in slots on the deck and run to the curb. The slots are filled with epoxy. The wires running along the curb to the system control box are encased in a fillet of air-entrained concrete.

Secondary or Surface Anode. A 40 mm layer of conductive asphalt is applied to the deck after placement of all anodes and other hardware. The composition and specified properties of the typical mix are shown in Table 2. The deck is not tack-coated.

Rectifier and Control Hardware. Rectifiers allowing the option of constant current or constant voltage operation, or operation under constant potential, are specified. Potential control is preferred and it has been found over the long term that the graphite probes provide a stable and reliable reference for the rectifier. Protection of the embedded steel is considered adequate when the potentials measured by the voltage probes in contact with the coke mix are between -0.80 and -1.25 V. A maximum capacity for each rectifier of 8 V/4 A is normally specified, with one rectifier feeding a maximum 200 m length of deck.

This protection system has some proven advantages. Installation costs can be kept down because the system is not easily damaged, does not require proprietary products or processes, and can be installed by a capable general contractor.

Because of the low resistance between anode and ground, the systems have extremely low power requirements, and the coke-asphalt surface anode provides an even distribution of current over the deck surface and permits dissipation of any gases which form. The system can be easily repaired if damage occurs, since the coke-asphalt layer does not bond to the deck surface. The appearance of the structure is maintained and a normal driving surface is provided to the motorist.

Typical operating characteristics for selected systems are given in Table 3. The systems shown vary over a range of sizes and ages. Current densities for the decks are generally in the range of 2.1 to 5.4 mA/m^2 (0.2 to 0.5 mA/ft^2) though some, such as the Humber River bridges, operate at lower power levels. When the current and voltage data shown in Table 3 were recorded, the potentials measured on each deck met the Ministry's protection criteria.

In order to maintain these potential levels throughout all seasons of the year, some variation in rectifier output is normal. Winter current levels are generally lower than those recorded during the summer months. Total current output for the Grand River Bridges at Paris, Ontario has varied from winter lows of 1.2 A in February 1981 and 1.0 A in December 1983 to typical summer levels of 2.5 A and 2.0 A in 1981 and 1986 respectively. For all readings, probe values lay within the specified voltage range.

Resistance between anode and ground is typically very low, resulting in the low operating voltages shown in Table 3. Attempts are made to reduce any voltage (IR) drops due to extremely long decks. For example, relatively heavy wire is used for anode feeder wires and for the ground buses in order to minimize resistance over very long wire lengths.

The costs of seven cathodic protection systems, installed in three contracts during 1984 and 1985, are given in Table 4. Typical costs for all cathodic protection items in the two larger contracts were between $45 and $55 Cdn. per square metre (between $4 and $5 per square foot) of deck area. Higher unit costs were experienced for the North Otter Creek structure because of the small size of the bridge, its relatively remote location, and the fact it was the only structure in the contract. The conductive asphalt used was typically priced at two to three times the cost of the conventional asphalt for the wearing course.

The figures given in Table 4 do not include costs due to concrete repair, other rehabilitation work carried out as part of the contract, or traffic control costs. Typically, cathodic protection installation would be timed to coincide with other major rehabilitation work on a structure. The figures shown are comparable to costs for conductive overlay, slotted non-overlay, and distributed anode systems reported for the United States (7).

EXAMINATION OF THREE BRIDGE DECKS

During the summer of 1985, three bridge decks were examined to determine the effectiveness of the cathodic protection, the condition of the concrete deck slab, and the condition of the various components of the cathodic protection systems.

The three decks selected for examination were Bridge 9 (in the 401/Don Valley Parkway Interchange), the two Grand River Bridges (on Highway 401), and the Atherly Narrows Bridge (on Highway 12).

Bridge 9, shown in Figure 1, was one of the first three decks in the Province to receive cathodic protection, in July 1974. A relatively small section of the bridge, 33.5 m x 8 m (110 ft x 26 ft), was protected. The coke layer placed on the deck was composed of 80% coke and 20% asphalt, and both graphite and iron primary anodes were used. It can be seen from the deck plan shown in Figure 2, that a large number of anodes were used. This overdesign was deliberate in order to allow optimum anode spacings to be investigated. The deck has typically been powered by only three anodes. The deck has been under almost constant protection since 1974, with no operational problems.

The twin Grand River Bridges were protected in 1976. This represented the Ministry's first attempt to protect a "large" structure - each structure was 238 m (780 ft) in length and 13 m (42 ft) wide. The bridges are shown in Figure 3. Each bridge was powered by a single string of anodes along the deck centerline. These bridges also represented the first use of a stone-modified coke mix and recessing of all the deck hardware. Problems in achieving uniform protection on the decks had been experienced since installation of the system. Although findings from this installation had provided useful input to later projects, the reasons for the system's lack of success were not understood.

The third bridge examined, at Atherly Narrows, received cathodic protection in 1982. This bridge is shown in Figure 4. It is the only one of the three decks examined which was constructed in accordance with current Ministry specifications and which would meet today's cathodic protection standards.

Methods of Evaluation.

First, each structure was visually examined for signs of deterior-

ation. Cores were removed from each deck to allow visual examination of the conductive mix and of the underlying concrete. Resistivity of the conductive mix was measured. Chloride contents of the concrete were measured. Adequacy of the concrete air void system characteristics was examined in cores removed from areas exhibiting surface deterioration.

Half-cell potential measurements were carried out on sections of the deck exposed by coring, using a portable copper-copper sulfate half-cell placed directly on the concrete surface. Instant-off potentials and potential shifts during short and long term depolarization, were obtained. The surface potential data were compared to data from the permanently embedded reference cells and voltage probes, to evaluate the protection offered to the deck and to compare protection criteria.

Testing Program - Bridge 9.

An initial concern with this system had been the stability of the conductive mix. However, when the deck was examined in 1985, there was no visible evidence of instability - no rutting or unusual cracking - in the protected portion of the deck. Some cracking of the asphalt surface had occurred on both the protected and the unprotected areas of the deck, but the cracks were random and consistent with those seen on other asphalt-covered decks of similar age and traffic loading.

Six four-inch diameter cores were removed from the deck, to expose the concrete surface. (Core locations are shown in Figure 2). The conductive mix appeared to be in excellent condition, with no evidence of stripping of the asphalt or other deterioration.

The coke-asphalt layer of the cores was very moist when removed from the deck and remained moist for several hours, indicative of the high void content of the mixture. Resistivity of the coke layer measured on three cores was 1.10. 1.04, and 1.0 Ω.cm, indicating excellent conductivity.

The deck concrete exposed by the coring was in good condition, with no visible scaling or evidence of acid attack at the coke-asphalt/concrete interface.

No primary anodes were exposed, but resistance between each individual anode and ground was measured and compared to readings made in 1974. The groundbed resistance of six of the twenty-three anodes had more than doubled over the eleven year period. This could be indicative of poor contact between the anodes and the coke-asphalt, or of damaged wires or connections. Groundbed resistance of the other anodes compared closely to the 1974 values. Asphalt will be stripped from the entire surface of Bridge 9 in 1987 during highway resurfacing, providing an excellent opportunity for an examination of the anodes and conductive mix on the protected portion of the deck. It will also allow comparison between the relatively small portion of the deck which has been cathodically protected, and the remainder of the deck which was waterproofed and paved.

The current density applied to the deck at the time of the investigation was 2.3 mA/m^2 (0.21 mA/ft). Polarized potentials on the graphite anodes were between -0.85 and -1.19 V, indicating protection. Copper-copper sulfate cell potentials, measured on the concrete near the graphite anodes, averaged -0.87 V, which satisfies -0.85 V, the standard NACE protection criterion (8) for piping.

An average shift in potential of 230 mV occurred within three hours of switching the system off, with shifts at all locations of 100 mV or greater. (This meets the proposed NACE protection criteria for steel in concrete, of a 100 mV shift four hours after switching off (9)). After twenty-eight days, the average potential shift was 630 mV.

Table 5 compares polarized potentials measured on the graphite anodes, copper-copper sulfate potentials measured on the concrete surface, and surface potential shifts during depolarization. The three criteria described would indicate that steel in the structure is protected. The protection offered appeared to be evenly distributed.

This cathodic protection system continues to operate.

Grand River Bridge.

Since installation, embedded instrumentation (zinc-zinc sulfate reference cells and graphite voltage probes) had indicated that this system operated inefficiently and could not meet the Ministry's protection criterion. An attempt to improve the marginal protection offered to the deck by the addition of extra rectifiers to minimize resistance drop over very long anode supply leads, was not successful.

One of the cores removed from the deck in 1985 showed considerable scaling of the concrete surface. Analysis of the air void system showed that, although the air content was acceptable, the void spacing and specific surface of the voids were inadequate for satisfactory air entrainment, and poor resistance to freeze-thaw action would be anticipated. The tendency of the conductive mixture to retain moisture had resulted in saturation of the concrete surface in areas where drainage was poor, and where the concrete was of marginal quality surface scaling resulted.

At the present time, decks which are candidates for application of cathodic protection must have an adequate air void system which is defined (6) as an air content of more than 3 percent, a spacing factor less than 0.20 mm, and a specific surface exceeding 24 mm^2/mm^3. Scaling problems such as those seen at Grand River would not be expected to occur in decks protected after 1977.

The cores removed showed the conductive mix to be in good condition. Unlike Bridge 9, the mix used on the Grand River Bridges was modified by the addition of stone to increase stability. Resistivities of 4.78 and 5.21 Ω.cm were measured on two of the cores removed, roughly five times the resistivities measured on Bridge 9. These values are also well above the specified maximum resistivity of the conductive mix (3 Ω.cm).

Average thickness of conductive asphalt on three cores was 17.5 mm, considerably less than the specified 40 mm depth. Both the high resistivity and insufficient thickness of coke-asphalt measured were judged to be contributors to the poor performance of the system.

At the time of examination, current output to the system was insufficient to maintain potentials sensed by all the graphite voltage probes at levels more negative than -0.80 V. Copper-copper sulfate potentials measured on the deck surface averaged only -0.53 V. Potential shifts after three hour depolarization averaged 42 mV, only reaching 100 mV approximately three weeks after switching off. The wide variations in data from both voltage probes and surface cells indicated a very uneven distribution of current on the deck.

Joint repairs were required on the Grand River Bridges in 1986, necessitating the removal of 35 mm of the asphalt wearing course of the deck in order to restore a proper profile. When this work was undertaken, it was found that considerably less than the specified depth of conductive mix and wearing course was present. The thickness of the conductive mix was inadequate, reduced to 5 mm in some areas along the deck centerline. The coke mix was badly spalled along the centerline joint. Figure 5 shows the conductive mix after the wearing course had been removed by scarifying. The single line of anodes powering each deck was also exposed in some areas, allowing the anodes to be examined. While the iron primary anodes showed

no evidence of corrosion, the conductive asphalt had deteriorated in the vicinity of some of the primary anodes so that contact between the anode and conductive mix was poor. The combined effects of insufficient thickness of conductive mix, lack of continuity across the centerline, poor anode/conductive mix contact, and an insufficient number of anodes were judged to account for the previous problems with protection and current distribution.

The repair activities provided an opportunity to examine fairly extensive areas of the deck surface. There was evidence of severe scaling of the concrete surface in poorly drained areas of the deck along curbs and joints, with some very minor scaling on the remainder of the deck. Exposed zinc-zinc sulfate reference cells showed visible damage. These cells had previously ceased to be useful due to instability. Exposed graphite voltage probes showed no evidence of deterioration. The exposed areas of the decks were sounded to detect delaminations. A number of small scattered areas of delamination were found, with some of the delaminations associated with the epoxy insulating patches placed on the deck during installation of the protection system. As no delaminations were found at the time of repair, these scattered delaminations provided another indication that the system was not working effectively during its lifetime.

This investigation reaffirmed the need to confine use of this type of cathodic protection system to decks with adequate air void systems. Because the coke mix is porous and will hold water next to the concrete surface, it is important to provide good drainage to all areas of the deck.

Atherly Narrows Bridge.

The deck of the Atherly Narrows Bridge showed no visible signs of distress in 1985. The eight cores removed from the bridge indicated that the conductive mix was in excellent condition, with no stripping of the asphalt. The cores displayed no evidence of any deterioration such as scaling or acid attack of the concrete surface. The concrete deck appeared to be in very good condition. The asphalt wearing course also showed no signs of distress.

The structure was receiving a current density of 2.5 mA/m^2 (0.23 mA/ft^2) of deck surface. This had typically been sufficient to polarize the graphite voltage probes on the deck to an average of -1.08 V (well within the "protected" range). Readings made on the exposed sections of concrete surface, using the portable copper-copper sulfate cell, averaged -0.62 V. At all but two of the core locations, the potential shift after a three-hour period of depolarization, was in excess of 100 mV. The potential and three-hour potential shift values are given in Table 6 for eight locations. Long term depolarization is also shown. As seen here and typical for a number of other structures examined, more than 50% of the long term potential shift occurred within three hours of switching the system off. This emphasizes the need to ensure that power to a cathodic protection system is not interrupted, or more practically, the need to carry out regular monitoring of systems so that power cuts will not go undetecced for long.

Based on the installations in Ontario, it appears that in order to comply with the present protection criteria, current densities required by coke-asphalt deck protection systems are considerably less than those required by substructure protection systems (10).

Prompted by concern with this difference in current density requirements, an attempt was made to carry out an E-log I test on the Atherly Narrows Bridge to determine the current theoretically required to protect the structure. The test procedure described in Reference 11 was followed, using the conductive mix itself as the counter electrode, and monitoring two

graphite reference probes embedded in the deck. However, modification of the test procedure was necessary to arrive at reproducible test results. Rather than using an unfiltered power supply, a DC source was used, interrupting the current to record instant-off potentials. For purposes of comparison, tests were carried out using three-minute and ten-minute intervals between increases in applied voltage. Test results for the two embedded graphite probes monitored are shown in Table 7. Although these results were produced by a non-standard test procedure, it is interesting to note that protection current densities predicted appear very conservative compared to normal operating values (i.e. about double). However, the potential shifts corresponding to the E-log I current are much less than those generally experienced at normal operating current densities.

It was also observed that the predicted protection current decreased as the time interval was increased from 3 to 10 minutes. From these observations, it appears that time influences predicted protection levels on such a structure to a very large extent, and that a rapid test may not be the most appropriate to evaluate this particular situation. Following the E-log I test, a current 50% of the less conservative protection current predicted by the test was applied to the deck. After only five days of operation, polarization shifts recorded by the graphite cells were very similar to those encountered during both E-log I tests. This emphasizes the time-dependent nature of polarization levels in these systems.

SUMMARY

The performance of the Ministry's standard system for bridge deck protection is encouraging. The present specifications are producing systems that function effectively and reliably to control corrosion of embedded reinforcing steel. Where problems have arisen, these occurred on experimental decks installed in the period 1974-6. The experience gained from these installations was invaluable in developing the design criteria for the standard cathodic protection systems now in use.

Both primary and secondary anode components of the system have proven durable. No visible consumption of the iron primary anodes has occurred after many years of operation and their rugged construction has prevented damage during installation. Recessing of these anodes and their lead wires in the deck surface has ensured that repairs to deck surfacing can be carried out if necessary without any damage to the cathodic protection hardware.

An objection often raised to protection systems using conductive asphalt is the possible instability of the mix under heavy traffic loads (7, 12). This instability has not been experienced on Ontario decks. Even the early mix design which was composed only of coke and asphalt and which might have been expected to exhibit instability, was experiencing no problems after twelve years of operation on Bridge 9. Neither have problems been encountered with the later stone-modified mix, even under the heaviest freeway traffic loadings.

Electrical hardware in use has also proven durable and reliable. Lightning strikes have caused several power interruptions in the past, although no such problems have been experienced with the rectifiers now in use. The least reliable component of the system has been the zinc-zinc sulfate reference cells. The use of these cells will be discontinued, and graphite probes will be embedded at the level of the steel. The graphite probes have demonstrated reliability when used as embedded reference cells in substructure cathodic protection systems.

To date, the use of bridge deck cathodic protection in Ontario has been limited. This is due in part to the fairly strict guidelines for selection of structures for application of cathodic protection. The cri-

teria that decks must have an adequate air void system prevents application to structures built before about 1958. Only structures showing less than 10% surface spalling and delamination are considered candidates for cathodic protection because the expense of making concrete repairs makes the installation of a concrete overlay a more economical alternative. However, in programming structures for repair, priority is usually given to those structures in the worst condition and, by the time a structure is rehabilitated, it is too late for cathodic protection. Although cathodic protection is a powerful method of arresting corrosion activity, its use is not being maximized at the present time, because funds are not available to protect structures before extensive spalling and delamination occurs. The ideal time to apply cathodic protection to corroding highway structures would be before physical distress develops.

There are no plans at the present time to make changes in the Ministry's standard method for the cathodic protection of bridge decks. The standard conductive mix system described is judged to be performing adequately. Properly constructed, it is capable of providing durable effective corrosion protection at costs competitive with other repair methods. Future work in the area of deck cathodic protection will focus on streamlining monitoring and maintenance procedures, and improving the existing standard documents outlining the installation process. The application of sealants to deck slabs with marginal air void systems, in order to prevent surface scaling, will also be investigated. Reliable field tests are required to assure the quality of the coke mix. Development of equally effective standardized protection methods for bridge substructures is also a priority (10).

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TABLE 1. CATHODICALLY PROTECTED BRIDGE DECKS IN ONTARIO 1974 - 1985

SITE NO	BRIDGE	HIGHWAY	YEAR INSTALLED
22-092	Duffins Creek	7	1974 Re-applied 1977
19-064	Medway Creek	7	1974
37-323	Bridge No. 9	DVP/401	1974
42-067	Paint Lake	117	1975
33-141(A)	Grand River (2 bridges)	401	1976
29-092	Nadawaska River	515	1978
31-085	South Nation River	31	1978
06-257	Gracie Sideroad UP	401	1978
34-129	CPR and CNR OH	QEW	1979
37-188	Humber River (4 bridges)	401	1979
18-176	Victoria Avenue UP	QEW	1980
01-024	Grand River at Paris	2	1980
37-186	CNR OH (2 bridges)	401	1981
37-341	Yonge Street OP	401	1982
42-141(A)	Gull River (2 bridges)	11	1982
30-074	Atherly Narrows	12	1982
31-201	County Road No. 1 UP	401	1983
03-041	Clyde Avenue OP	17	1984
03-044	Carling Avenue EB OP	17	1984
03-045	Kirkwood Avenue OP	17	1984
03-046	Carling Avenue WB OP	17	1984
03-048	Island Park Drive OP	17	1984
05-329	North Otter Creek	9	1984
18-197	St. David's Road OP	58	1984
12-171	Maitland River Bridge	21	1985

TABLE 2: COMPOSITION AND PROPERTIES OF COKE-ASPHALT MIX

Material	% by Mass
Coke-breeze (-3 screen), % wt.	45
Stone (-5/8 + 4 screen), % wt.	40
Sand (-4 screen), % wt.	15
Asphalt (85/100), % of total aggregate	15.5
Maximum air void content, % vol.	3
Maximum resistivity, Ω.cm	3

TABLE 3: TYPICAL SYSTEM OPERATING CHARACTERISTICS

BRIDGE	AREA (ft^2)	AREA (m^2)	CURRENT ON DECK (mA/ft^2)	DENSITY SURFACE (mA/m^2)	SYSTEM VOLTAGE (V)	MEETING MTC CRITERIA
Bridge 9	2750	256	0.26	2.8	2.3	yes
Humber River 1	11220	1042	0.27	2.9	2.5	yes
2	18750	1743	0.17	1.8	3.0	yes
3	16630	1548	0.18	1.9	2.6	yes
4	7905	735	0.10	1.1	2.0	yes
Paris	33990	3160	0.12	1.3	1.8	yes
Atherly Narrows	14110	1310	0.24	2.6	2.4	yes
Clyde Ave. WB	3950	367	0.28	3.0	5.3	yes
Island Park	9346	868	0.33	3.6	4.2	yes
Kirkwood Ave	7683	714	0.34	3.6	4.3	yes
St. David's Rd	6450	600	0.54	5.8	2.2	yes

TABLE 4: COST COMPARISON FOR SYSTEMS INSTALLED DURING 1984 AND 1985
(All Figures in Canadian Dollars Per Square Foot of Deck Area)

COST ITEMS	STRUCTURES						
	NORTH OTTER CREEK	CLYDE AVE.	CARLING AVE. EB	KIRKWOOD AVE.	CARLING AVE. WB	ISLAND PARK DRIVE	MAITLAND RIVER
· Coring for Anodes · Sawcutting · Power Supply · Materials · Installation of CP System	6.34	3.64	3.90	3.69	3.92	3.14	2.66
· Conductive Asphalt	2.02	1.12	1.12	1.12	1.12	1.12	1.47
Total CP Items	8.36	4.76	5.02	4.81	5.04	4.26	4.13
Deck Area in Contract: ft^2	1736	37095					25230
m^2	161	3446					2344

TABLE 5: POTENTIAL AND POTENTIAL SHIFT MEASUREMENTS, BRIDGE 9
Current Density on Deck = 2.3 mA/m^2 (.21 mA/ft^2)

All potential readings are expressed in volts

CORE IDENTIF.	JUN 13 1985			JUL 15 1986
	POTENTIAL ON GRAPHITE ANODES (INST OFF)	Cu-$CuSO_4$ POTENTIALS (INST OFF)	3 HR POTENTIAL SHIFT	LONG TERM POTENTIAL SHIFT
4	-1.34	-0.97	0.22	0.60
8 centreline	-1.06	-0.90	0.10	0.67
8 curb		-0.80	0.21	0.58
14	-0.85	-0.79	0.28	0.66
21 centreline	-1.19	-0.91	0.30	0.60
21 curb		-0.91	0.29	0.67
AVERAGE	-1.04	-0.88	0.23	0.63

TABLE 6 POTENTIAL AND POTENTIAL SHIFT MEASUREMENTS, ATHERLY NARROWS
Current Density on Deck = 2.5 mA/m² (.23 mA/ft²)

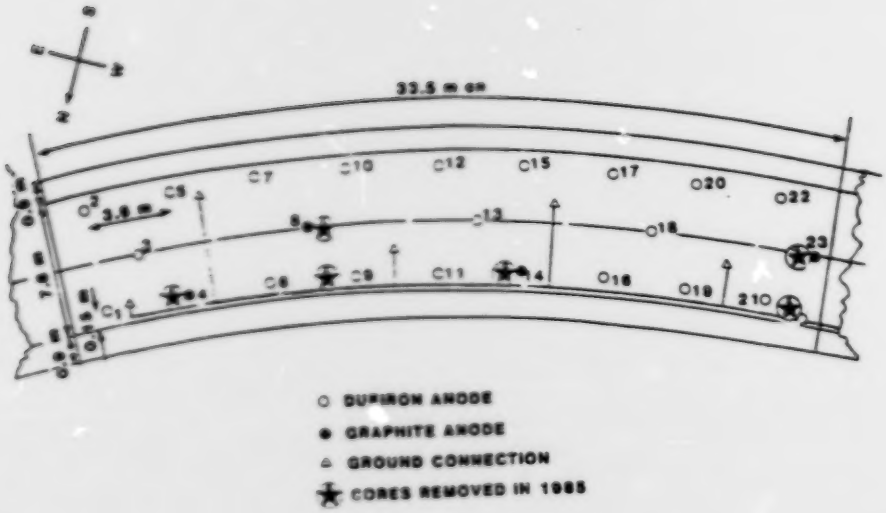
All potential readings are expressed in volts

CORE IDENTIF	JULY 18, 1985		OCT 30 1985
	Cu-CuSO₄ POTENTIALS (INST OFF)	3 HR POTENTIAL SHIFT	LONG TERM POTENTIAL SHIFT
1 centreline	-0.67	0.05	0.21
2 centreline	-0.28	0.09	0.12
2 curb	-0.40	0.16	0.22
3 centreline	-0.71	0.14	0.27
3 curb	-0.64	0.17	0.25
4 curb	-0.60	0.17	0.25
8	-0.96	0.14	0.26
10	-0.74	0.20	0.19
AVERAGE	-0.66	0.14	0.22

TABLE 7 RESULTS OF MODIFIED E-LOG I TEST, ATHERLY NARROWS

TEST PARAMETER	CELL	3 MIN INTERVALS	10 MIN INTERVALS
Corrosion Current, Icorr (mA)	#8 #10	4600 6500	3500 4600
Protection Current, Iprot (mA)	#8 #10	10000 11000	7000 7800
Protection Potential, Eprot (mV)	#8 #10	-290 -442	-112 -431
Potential Shift, E(mV)	#8 #10	-26 -53	-36 -54
Average Current Density for Protection (mA/m²) (mA/ft²)		8.07 .75	5.65 .53

Figure 1: Bridge 9



○ DURIRON ANODE
● GRAPHITE ANODE
△ GROUND CONNECTION
★ CORES REMOVED IN 1985

Figure 2: Bridge 9. Plan view showing layout of cathodic protection system hardware, and location of cores removed in 1985

Figure 3: Grand River Bridges

Figure 4: Bridge over Atherly Narrows

Figure 5: Grand River Bridge. The conductive mix is shown, after removal of the wearing course by scarifying.